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(54) Spin-valve structure and method for making same

(57) The present invention concerns a spin-valve structure comprising a first and a second free ferromagnetic layer and an antiferromagnetic layer positioned between said first and second free ferromagnetic layer, characterised in that said first free ferromagnetic layer is positioned on a semiconductor substrate. It further concerns a method for producing a spin-valve structure, comprising the step of electrodeposition of said spin-valve structure on a semiconductor substrate.

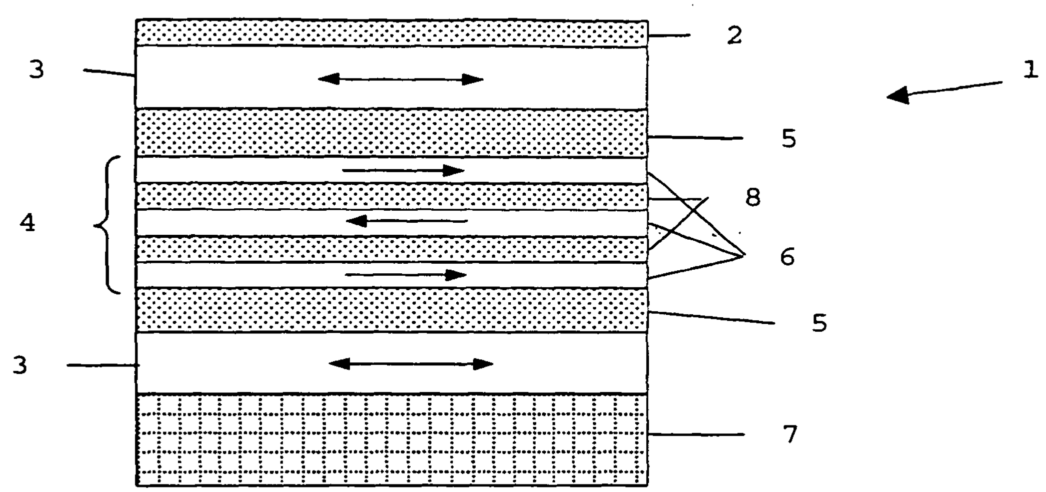

Fig. 1

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Description

Field of the invention

This invention relates to the structure and fabrication of magnetic devices, having a spin-valve structure.

State of the art

The giant magnetoresistance (GMR) effect is of large interest for applications in magnetoresistive read and write heads and for magnetic sensors. GMR magnetic multilayers exhibit strong coupling characteristics and thus high saturation fields. New magnetic field sensors having a spin-valve structure have been disclosed. These structures have the advantage of high magnetoresistance (MR) signals and high sensitivities at lower fields (J.C.S. Kools, Exchange-Biased Spin-Values for Magnetic Storage, IEEE Trans. Magn., 32 (1996) 3165-3184), which are important considerations for many sensing applications. The production of films, showing these effects, is usually achieved by sputtering techniques.

Recently several research groups have shown that the single bath electrodeposition technique, is an attractive technique for the production of GMR multilayers (W. Schwarzacher and D.S. Lashmore, Giant magnetoresistance in electrodeposited films, IEEE-Trans. Magn., 32 (1996) 3133-53), but due to the above mentioned high saturation fields, they are unattractive for low field sensing. The largest sensitivity so far obtained in electrodeposited multilayers has been 0.1% per Oe (R. Hart, M. Alper, K. Attenborough and W. Schwarzacher, Giant magnetoresistance in Ni-Co-Cu/Cu superlattices electrodeposited on n-type (100) GaAs substrates, Proc. 3rd International Symposium on Magnetic Materials, Processes and Devices, Electrochem. Soc. Proc., 94 (1994) 215-221). A superlattice is a multitude of ferromagnetic and antiferromagnetic layers. The ferromagnetic layers can be coupled or uncoupled. If electrodeposition is to be considered for future sensing applications, higher sensitivity at lower switching fields must therefore be achieved.

A spin-valve is a structure with a thin nonmagnetic spacer layer sandwiched between two ferromagnetic (FM) layers, which have different coercivities. The coercivity of a magnetic material reflects the resistance to a change of the orientation of the magnetic field when a magnetic (or electric) field is externally applied. In sputtered spin-valves this can be achieved by having different layer thickness, different materials or by pinning one of the layers to an antiferromagnetic (AF) layer, leaving the other magnetic layer free to rotate. The magnetisation alignment of the ferromagnetic layers can be changed from antiparallel (high resistance state) to parallel (low resistance state) depending on the externally applied magnetic field.

A recent advance in spin-valve design used to replace the typical AF materials, e.g., FeMn or NiO, has been the implementation of an artificial or synthetic antiferromagnetic subsystem (H.A.M van den Berg, W. Clemens, G. Gieres, G. Rupp, W. Schelter and M. Vieth, GMR sensor scheme with artificial antiferromagnetic subsystem, IEEE Trans. Magn., 32 (1996) 4624-4626.)) or SyAF (J.L. Leal and M.H. Kryder, Spin-valves exchange biased by Co/Ru/Co synthetic antiferromagnets, J.Appl.Phys. **83**, 3720 (1997)) These new spin-valve structures are comprised of a FM layer separated by a Cu spacer layer from the AAF subsystem, which itself consists of a few strongly coupled Co/Cu bilayers or Co/Ru/Co respectively. They have an added advantage over the AF layers of improved resistance against corrosion and higher processing temperatures.

Electrodeposition usually takes place on a conductive seed layer, typically Cu. If this seed layer cannot be removed, problems of current shunting and signal loss occur when measuring the magnetoresistive properties of the electrodeposits.

Aims of the invention

A first aim of the present invention is to provide a novel magnetic device capable of high magnetoresistive signals and high sensitivities at low fields.

Another aim of the present invention is to provide a novel magnetic device of which the properties can be determined by varying its construction parameters, and to provide a novel magnetic device that can be used for several purposes by varying its mode of operation.

Another aim of the present invention is to provide a new magnetic memory device that can show multi-value memory capacity.

A further aim of the present invention is to provide a novel method for producing a magnetic sensor capable of high magnetoresistive signals and high sensitivities at low fields.

Another aim of the present invention is to provide a novel low-cost fabrication method for spin-valve structures.

General description of the invention

The present invention concerns a spin-valve structure comprising a first and a second free ferromagnetic layer and an antiferromagnetic layer positioned between said first and second free ferromagnetic layer, characterised in that said first free ferromagnetic layer is positioned on a semiconductor substrate. Said first free ferromagnetic layer is preferably in direct contact with said semiconductor surface.

Between the first free ferromagnetic layer and the antiferromagnetic layer and between the second free ferromagnetic layer and the antiferromagnetic layer there is preferably a nonmagnetic layer.

In a free ferromagnetic layer, the orientation of the magnetic fields can be changed with an externally ap-

plied electrical or magnetic field.

The spin-valve structure can be further characterised in that said antiferromagnetic layer is an Artificial Antiferromagnetic layer or a Synthetic Antiferromagnetic layer. Said semiconductor substrate can be a GaAs or a Si substrate.

Said first and/or second free ferromagnetic layer can comprise Co, but can also comprise NiFe and CoFe.

Preferably, the first free ferromagnetic layer, that is positioned on said semiconductor surface has a higher coercivity than the other free ferromagnetic layer.

The magnetic and structural properties of said first free ferromagnetic layer can influenced by the structure of the surface and/or the lattice structure of the semiconductor substrate on which it is positioned.

In a preferred embodiment, there is an electrical barrier between the first free ferromagnetic layer and the semiconductor surface. Said electrical barrier can be a schottky barrier or a tunnel barrier. Said electrical barrier can prevent shunting currents and protect said spin-valve structure against electrostatic discharge.

The antiferromagnetic layer can comprise Cu layers and Co layers positioned therebetween, said Cu layers being thin enough as to increase magnetic coupling between said Co layers. Said antiferromagnetic layers can act as a single hard layer.

Said spin-valve structure can act as a magnetic memory device, preferably a magnetic memory device having more than two memory states.
Said magnetic memory device can be set using current pulses of predefined magnitude and pulse width. For achieving a different memory setting, current pulses can of a fixed magnitude and a variable pulse width, or current pulses can be of a variable magnitude and a fixed pulse width.

Another aspect of the present invention is a method for producing a spin-valve structure, comprising the step of electrodeposition of said spin-valve structure on a semiconductor substrate.
Said step of electrodeposition preferably comprises the following steps:

- electrodeposition of a first ferromagnetic layer on a semiconductor substrate,
- electrodeposition of an antiferromagnetic layer on the first ferromagnetic layer, and
- electrodeposition of a second ferromagnetic layer on the antiferromagnetic layer.

In a preferred embodiment, said electrodeposition steps are performed in a single electrolyte bath. Said electrolyte can comprises several elements, said elements being selected to be deposited by an applied electrodeposition voltage.

The method can further comprise a selection or a changing step of the surface structure of said semiconductor substrate prior to the electrodeposition step.

A further aspect of the invention is the use of the spin-valve structure as described higher obtainable by the method as described higher as a sensing element for contactless position, distance and movement sensing.

Another aspect of the present invention is the use of the spin-valve structure as described higher obtainable by the method as described higher as a sensing element for angular position sensing.

Another aspect of the present invention is the use of the spin-valve structure as described higher obtainable by the method as described higher as a sensing element for indirect measurement of physical parameters through the change in resistance of the multilayer structure.

Another aspect of the present invention is the use of the spin-valve structure as described higher obtainable by the method as described higher as a magnetic device in a magnetic memory circuit for building a Magnetic Random Access Memory. Said magnetic device can have a multivalue magnetic memory.

Another aspect of the present invention is the use of the spin-valve structure as described higher obtainable by the method as described higher as an element of logic gates comprised in a logic device.

Another aspect of the present invention is a method of operating the spin-valve structure comprising a barrier as described higher, whereby currents are confined in-plane by said barrier.

A final aspect of the present invention is a method of operating the spin-valve structure comprising a barrier as described higher, whereby currents can cross said barrier due to the applied voltage over said barrier.

Detailed description of the invention

The aims of the invention are met in the present invention. A spin-valve deposited on a semiconductor substrate results in a highly sensitive magnetic sensor. The production of a magnetic sensor comprising the electrodeposition of a spin-valve structure on a semiconductor substrate, provides a sensor capable of high magnetoresistive signals and high sensitivity for low fields.

The process according to the invention comprises an electrodeposition step. Electrodeposition usually takes place on a conductive seed layer, typically Cu. If this seed layer cannot be removed, problems of current shunting and signal loss occur when measuring the magnetoresistive properties of the electrodeposits. To avoid this problem, the spin-valves are grown on a GaAs substrate, which eliminates the current shunting through the formation of a schottky barrier at the metal/semiconductor interface.

Preferably, a single bath electrodeposition technique is used.

Since in the case of the single bath electrodeposition technique one is restricted to layers consisting of elements present in the electrolyte, the implementation

of such an AAF subsystem is a viable option in order to produce electrodeposited spin-valve structures.

Substrate choice for electrodeposition

The spin-valve structure is grown on a semiconductor substrate, GaAs is used as an example throughout this description. This provides a barrier contact between the metallic multilayer and the substrate. The approach of growing a spin-valve structure on a semiconductor also solves the problem of large shunting currents in the structure. The barrier contact further allows several modes of operation, depending on the voltage applied over the barrier contact, since current will only flow over the barrier contact for certain voltage ranges.

The growth on the semiconductor has another advantages. Through the difference of the substrate structure and/or surface conditions in comparison to Cu or other standard template layers, the structural properties and the magnetic anisotropy properties of the magnetic film in contact with the semiconductor substrate are different. This cancels the need for an additional pinning layer or other additional metal to change the magnetic properties. The structure (and thus the coercivity) of the ferromagnetic layer that is positioned directly on the semiconductor surface is influenced by the structure of the substrate and by the condition of the surface (roughness, lattice, ...). Even the use of a magnetic field during deposition can be avoided. Hence the semiconductor substrate is clearly determining some of the important properties of the sensing element.

The semiconductor can be a semiconducting polymer, or a polymer that makes a schottky or other barrier contact with a metal deposited thereon. Also, the metal can be separated from the substrate by an insulating tunnelling barrier.

Method of deposition

The voltage for the deposition is high enough to ensure carrier transport through/across the insulating barrier. In sensing operation, the sense current through the magnetic element structure is not entering the semiconductor substrate because of the lower voltage applied across the barrier.

The barrier has another advantage in specific cases where it can prevent a large current to go through the spin-valve by deviating it into the substrate, hence offering an added feature in the design of components reducing the problem of breakdown or permanent failure due to transients such as Electrostatic Discharge or spikes on power and ground lines in circuits

Sub-micron structures without seeding/template layer and without the need for subtractive etching or lift-off: method of growing the spin-valve structure.

The electrodeposition can provide sub-micron structures without the need for subtractive etching or lift-off processes. When electrodepositing on the semiconducting substrate into a cavity, there is no need for a sacrificial layer and the cavity will be filled from the bottom up. This overcomes the problem of side-wall growth which may lead to void formation or at least a loss of the layer-by-layer growth, which is essential for the spin-valve elements.

Description of a preferred embodiment.

The invention will be further clarified with a non-limiting example of a preferred embodiment and figures.

Brief description of the figures

Figure 1 describes a schematic representation of a spin-valve structure according to a preferred embodiment of the present invention.

Figure 2 shows a schematic diagram of the experimental setup used for electrodeposition.

Figure 3 discloses the magnetoresistance and hysteresis loop, measured at 45°, as a function of applied field for an electrodeposited spin-valve structure.

In figure 4, magnetoresistance curves measured at angles of 0°, 45°, 65° with respect to the preferential crystal orientation in GaAs is shown.

Description of the structure of the spin-valve structure according to a preferred embodiment of the invention:

The sensor structure of the present invention is schematically represented in Fig. 1. A symmetric variant spin-valve structure is used, having two free ferromagnetic layers sandwiched around the AAF subsystem, with a thicker Cu spacer layer being used to uncouple the free ferromagnetic layers from the subsystem.

In this case the thickness of the spacing Cu layers inside the AAF is enlarged so as to reduce the coupling in the magnetic sublayers of multilayer. In this case the characteristics of a hard ferromagnet are achieved. The advantages of using an AAF (or a SyAF) in terms of corrosion resistance and processing temperatures are preserved.

The spin-valve structure according to the present invention comprises at least the following elements: two free ferromagnetic (FM) layers with different coercivity, spaced apart by a antiferromagnetic spacer layer, whereby one of the FM layers is positioned on the surface of a semiconductor substrate such as GaAs or Si.

Preferably, the spacer layer is an artificial antiferromagnetic layer and/or a synthetic antiferromagnetic layer.

A device according to a preferred embodiment of the present invention is described next and is drawn in figure 1.

The chosen sensor structure (1), deposited on a GaAs substrate (7) consists of two so-called free layers

of 10 nm Co (3) sandwiched around an AAF subsystem (4) by two 4.8 nm Cu uncoupling layers (5). The AAF subsystem (4) consists of three 2.7 nm Co layers (6) separated by Cu spacer layers (8). To increase the coupling between these Co layers (6), the thickness of the Cu spacer layers (8) has to be very thin, in our case, 3.2 nm. Finally, the structure is capped with a 4 nm Cu layer (2) to prevent oxidation of the top Co layer.

Description of the production process of the spin-valve structure according to the preferred embodiment of the invention:

Rectangular pieces are cut from an n-type (100)-GaAs substrate (Si doped 1018 cm^{-3}, from AXT). Electrical contact is made via an ohmic contact to the back of the wafer pieces and the edges are covered with Kapton tape to prevent solution leakage during the pre-cleaning steps and the electrodeposition.

Prior to electrodeposition, the oxides are removed from the GaAs surface by pre-treatment in an NH_3 solution followed by rinsing in deionised water. The sample is directly placed into a sulfate electrolyte (19), containing Co and Cu ions (see S.K.J. Lenczowski, C. Schoenenberger, M.A.M. Gijs, W.J.M. de Jonge, Giant magnetoresistance of electrodeposited Co/Cu multilayers, J. Magn. Mat., 148 (1995) 455-65). Deposition experiments are performed at room temperature and pH 3.3. A standard three electrode plating cell (11) is used with Ag/AgCl as the reference electrode (17), Pt as a counter electrode (23) and the substrate as the working electrode (21). All electrode potentials quoted are measured with respect to the reference electrode. Since each metal ion has its own characteristic deposition potential it is possible to control the composition of the electrodeposited layers by choosing the appropriate potential provided by a potentiostat (15). In our case, we used -0.55 V to deposit pure copper and -1.1 V for the deposition of the magnetic Co-based layer. The deposition process was computer controlled (13) enabling the current flowing through the circuit to be monitored and integrated. When the chosen potential is applied to the substrate, a charge flows through the circuit which determines, via Faraday's law, the thickness of the deposit depending on the exposed deposition area. Once the charge corresponding to the desired thickness had been reached, the potential was automatically switched to deposit the next layer.

Properties of the spin-valve structure according to the preferred embodiment of the invention:

Magnetoresistive properties of the spin-valve sensor structure as disclosed in the preferred embodiment above were measured. Magneto-transport properties can be measured using a 4-point probe in a D.C. configuration up to 1.7 kOe and an alternating gradient field magnetometer (AGFM) can be used to measure the magnetisation curves of the samples. All measurements are performed at room temperature. A magnetoresistance (MR) (full line) as well as the corresponding hysteresis curve (dotted line) of this sample are shown in Fig. 3. These curves are measured under an angle of 45° with respect to the preferential crystal orientation of the GaAs ([110] orientation). The magnetoresistance curve shows three almost discrete resistance levels as a function of the magnetic field, which corresponds to well defined magnetisation configurations in the multi-layer structure, as can be seen in the hysteresis behaviour at those particular fields. This can be explained as follows.

Starting from saturation (+200 Oe) the magnetic field is decreased and as long as the alignment between the ferromagnetic layers is not altered, the resistance remains constant. At around -26 Oe the resistance abruptly increases which is due to one of the Co free ferromagnetic layers switching at that field. This field corresponds to the coercive field of the top free ferromagnetic layer whose magnetisation is now antiferromagnetically aligned, i.e. anti-parallel, with the magnetisation of the middle structure 4. This can be better understood by taking into account the different contributions of the ferromagnetic layers in the total magnetisation for this particular field, for which a strong decrease can be observed in the hysteresis behaviour. The sensitivity of the magnetoresistance during this transition corresponds to 0.32 %/Oe. When the second free ferromagnetic layer is switching, the MR ((Rmax-Ro)/Ro) reaches its maximum value of 5.4% at around -37 Oe, which corresponds to a sensitivity of 0.55 %/Oe. A rather broad plateau region in both curves ranges from -37 to -58 Oe. Upon decreasing the magnetic field further, the resistance decreases and becomes saturated at around -100 Oe.

If the substructure were a true AAF structure then one would expect to see a long tail in the magnetisation response. Since this is not present, the inner layers are not strongly AF coupled but are acting as a 'single' hard layer. Thus, the field at which the MR reaches saturation corresponds to the mean coercive field of this artificially hard layer.

The structure thus described can be visualised as two simple spin-valves which are equally contributing to a higher total magnetoresistance effect, as the number of spin-dependent scattering interfaces is doubled while the influence of spin-independent outer boundary scattering is reduced.

It can also be observed that the GMR peak positions, size and sensitivity of the films strongly varies with the angular positioning of the sample within the magnetic field and some typical examples of this are shown in fig. 4. The highest sensitivity reached so far is 0.67% per Oe. This angular dependence of the MR is evidence of a strong in-plane anisotropy, which might be one of the factors responsible for the unique spin-valve properties of these films. These properties also indicate that

the presented spin-valve structure has a strong potential towards sensor implementation.

The step that can be observed in the MR is caused by the difference in coercive field between both free ferromagnetic layers.

The possible explanations for the difference in coercivity :

- Structure on the substrate (grain size)
- Magnetic anisotropy induced by the semiconductor
- Gradient in Cu-content of the subsequent Co layers

But tailoring these coercivities actually opens up many more possibilities for sensor application. For example, if both plateau regions are expanded, e.g. the curve recorded at 65°, a multi-value memory element could be realised.

On the other hand, by matching the coercivities, a monotonous response of MR with field is possible and would dramatically increase the sensitivity of these structures, i.e., normal spin-valve behaviour.

Use of the spin-valve structure of the present invention:

The spin-valve structure according to the invention can be used as:

- A sensing element for contactless position, distance and movement sensing
- A sensing element for angular position sensing
- A sensing element for indirect measurement of other physical parameters through the change in resistance of the multilayer structure.
- A sensing element with increased resistance against over-voltage or over-current breakdown.
- A magnetic memory element in a magnetic memory circuit for building a Magnetic Random Access memory with ultra-small magnetic bits.
- A logic device where the magnetic devices fabricated using the disclosed details are used in the logic (latching) gates. The artificial hard ferromagnet structure has certain advantages for the fabrication of re-configurable logic to be used in Neural Nets and other future applications, where magnetic devices are already claimed to be useful.

The quick transition to the fully aligned state (high sensitivity of the structure in this field range) adds another advantage when such elements are intended for use in latching devices (sensing elements with memory or threshold detection functions) and reconfigurable logic gates. Further, the number of plateaus in the MR curve can be tailored to achieve a chosen logic function for a chosen number of inputs. The inputs will typically be current-pulses of a pre-defined magnitude and pulse-width, sent through a conductor which is inductively coupled to the magnetic element(s) in the gate-cell. The multiple values of the magnetic memory element can correspond to current-pulse magnitude (fixed pulse-width) or current-pulse width (fixed magnitude) values.

The magnetic elements according to the present invention can also be used as tuneable resistors with memory function for all applications where changing the value of a resistor can change the functioning of a circuit such as in the feedback of an Opamp, tuning of filters or oscillators, or MMIC circuits with integrated resistors to replace or to be integrated together with existing high precision resistors like NiCr. The tuning can be done with an external magnetic field and retains its value due to the built-in hysteresis of the magnetic element. In the case of soft magnetic materials, it can also be done with integrated current-lines, to bias the sensing elements. Self-biasing in the case of spin-valves must be taken into account (current in the spin-valve changes the magnetisation state and hence also the resistance value). This effect can be used to detect maximum values of currents.

Claims

1. A spin-valve structure comprising a first and a second free ferromagnetic layer and an antiferromagnetic layer positioned between said first and second free ferromagnetic layer, characterised in that said first free ferromagnetic layer is positioned on a semiconductor substrate.

2. The spin-valve structure as in claim 1, characterised in that said first free ferromagnetic layer is in direct contact with said semiconductor substrate.

3. The spin-valve as in claim 1 or 2, characterised in that between the first free ferromagnetic layer and the antiferromagnetic layer and between the second free ferromagnetic layer and the antiferromagnetic layer there is a nonmagnetic layer.

4. The spin-valve structure as in any of the claims 1 or 3, characterised in that said antiferromagnetic layer is an Artificial Antiferromagnetic layer or a Synthetic Antiferromagnetic layer.

5. The spin-valve structure as in any of the claims 1 to 4, characterised in that said semiconductor substrate is a GaAs or a Si substrate.

6. The spin-valve structure as in any of the claims 1 to 5, characterised in that said first and/or second free ferromagnetic layer comprises a material chosen from the group consisting of Co, NiFe and CoFe or a mixture thereof.

7. The spin-valve structure as in any of the claims 1 to 6, characterised in that the first free f rromagnetic layer that is positioned on said semiconductor sur-

face has a higher coercivity than the other free ferromagnetic layer.

8. The spin-valve structure as in any of the claims 1 to 7, characterised in that the magnetic and structural properties of said first free ferromagnetic layer are influenced by the structure of the substrate and/or the conditions of the surface of the semiconductor substrate on which it is positioned.

9. The spin-valve structure as in any of the claims 1 to 8, characterised in that the magnetic and structural properties of said first free ferromagnetic layer are influenced by the lattice structure of the semiconductor substrate on which it is positioned.

10. The spin-valve structure as in any of the claims 1 to 9, characterised in that between the first free ferromagnetic layer and the semiconductor surface there is an electrical barrier.

11. The spin-valve structure as in claim 10, characterised in that said electrical barrier is a schottky barrier or a tunnel barrier.

12. The spin-valve structure as in claim 10 or 11, characterised in that said electrical barrier prevents shunting currents and protects said spin-valve structure against electrostatic discharge.

13. The spin-valve structure as in any of the claims 1 to 12, characterised in that said antiferromagnetic layer comprises Cu layers and Co layers positioned therebetween, said Cu layers being thin enough as to increase magnetic coupling between said Co layers.

14. The spin-valve structure as in any of the claims 1 to 13, characterised in that said antiferromagnetic layers acts as a single hard layer.

15. The spin-valve structure as in any of the claims 1 to 14, characterised in that said spin-valve structure can act as a magnetic memory device.

16. The spin-valve structure as claim 15, characterised in that said magnetic memory device has more than two memory states.

17. The spin-valve structure as in claim 15 or 16, characterised in that said magnetic memory device is set using current pulses of predefined magnitude and pulse width.

18. The spin-valve structure as in claim 17, characterised in that said for achieving a different memory setting, current pulses are of a fixed magnitude and a variable pulse width.

19. The spin-valve structure as in claim 17, characterised in that said for achieving a different memory setting, current pulses are of a variable magnitude and a fixed pulse width.

20. A method for producing a spin-valve structure, comprising the step of electrodeposition of said spin-valve structure on a semiconductor substrate.

21. The method of claim 20, said step of electrodeposition comprising the following steps:

- electrodeposition of a first ferromagnetic layer on a semiconductor substrate,
- electrodeposition of a first nonmagnetic layer on the first ferromagnetic layer,
- electrodeposition of an antiferromagnetic layer on said first nonmagnetic layer,
- electrodeposition of a second nonmagnetic layer on the antiferromagnetic layer,
- electrodeposition of a second ferromagnetic layer on the second nonmagnetic layer.

22. The method as in claim 20, characterised in that said electrodeposition steps are performed in a single electrolyte bath.

23. The method as in claim 22, characterised in that said electrolyte comprises several elements, said elements being selected to be deposited by an applied electrodeposition voltage.

24. The method as in any of the claims 20 to 23, characterised in that the surface structure of said semiconductor substrate is selected or changed to a desired surface structure prior to the electrodeposition step.

25. Use of the spin-valve structure as in any of the claims 1 to 19 or obtainable by the method as in any of the claims 20 to 24 as a sensing element for contactless position, distance and movement sensing.

26. Use of the spin-valve structure as in any of the claims 1 to 19 or obtainable by the method as in any of the claims 20 to 24 as a sensing element for angular position sensing.

27. Use of the spin-valve structure as in any of the claims 1 to 19 or obtainable by the method as in any of the claims 20 to 24 as a sensing element for indirect measurement of physical parameters through the change in resistance of the multilayer structure.

28. Use of the spin-valve structure as in any of the claims 1 to 19 or obtainable by the method as in any of the claims 20 to 24 as a magnetic device in a

magnetic memory circuit for building a Magnetic Random Access Memory.

29. Use of the spin-valve structure as in claim 27, characterised in that said magnetic device has a multi-value memory.

30. Use of the spin-valve structure as in any of the claims 1 to 19 or obtainable by the method as in any of the claims 20 to 24 as an element of logic gates comprised in a logic device.

31. A method of operating the spin-valve structure as in any of the claims 9 to 18, whereby currents are confined in-plane by said barrier.

32. A method of operating the spin-valve structure as in any of the claims 10-19, whereby currents can cross said barrier due to the applied voltage over said barrier.

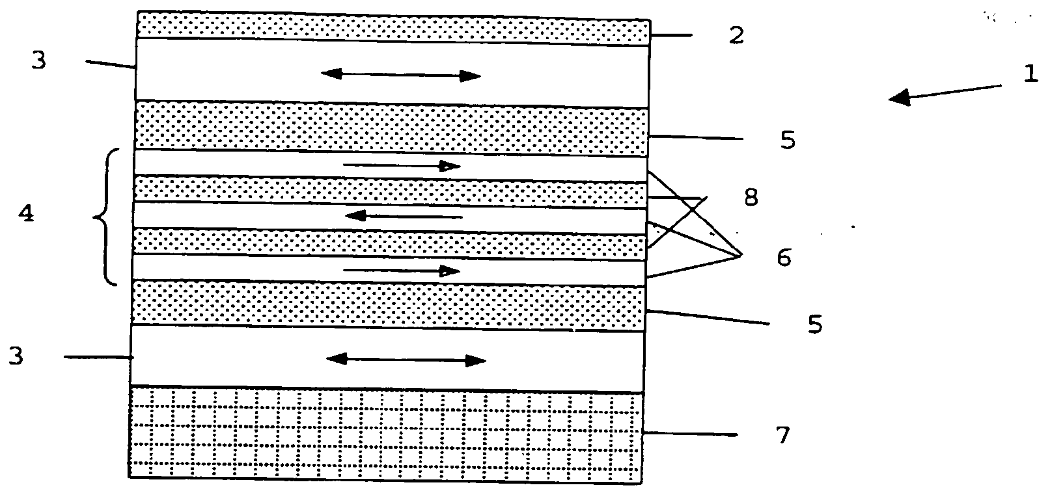

Fig. 1

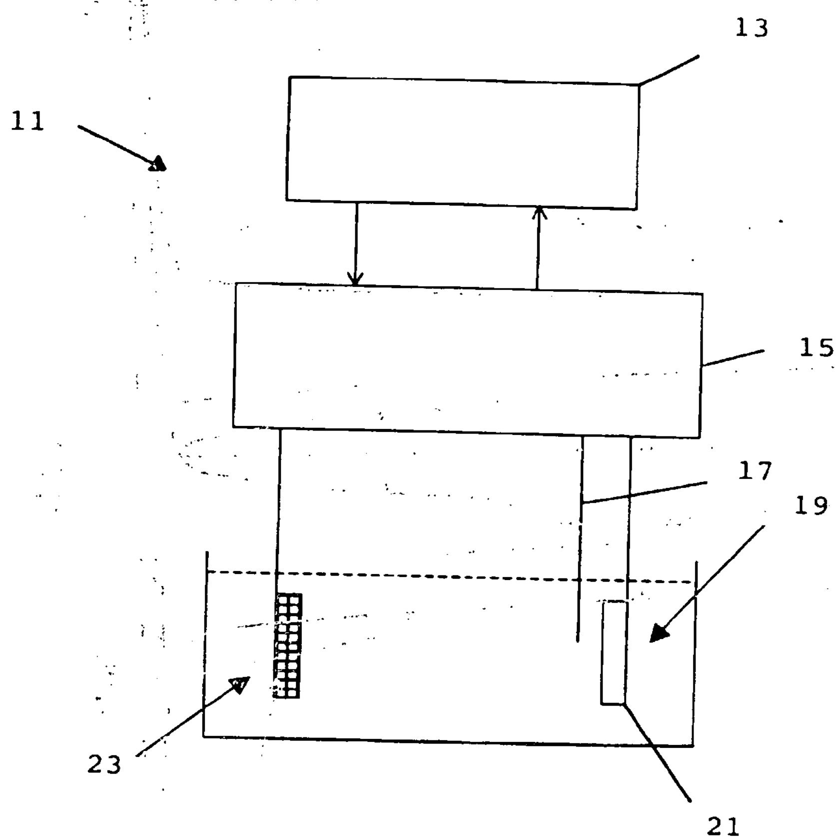

Fig. 2

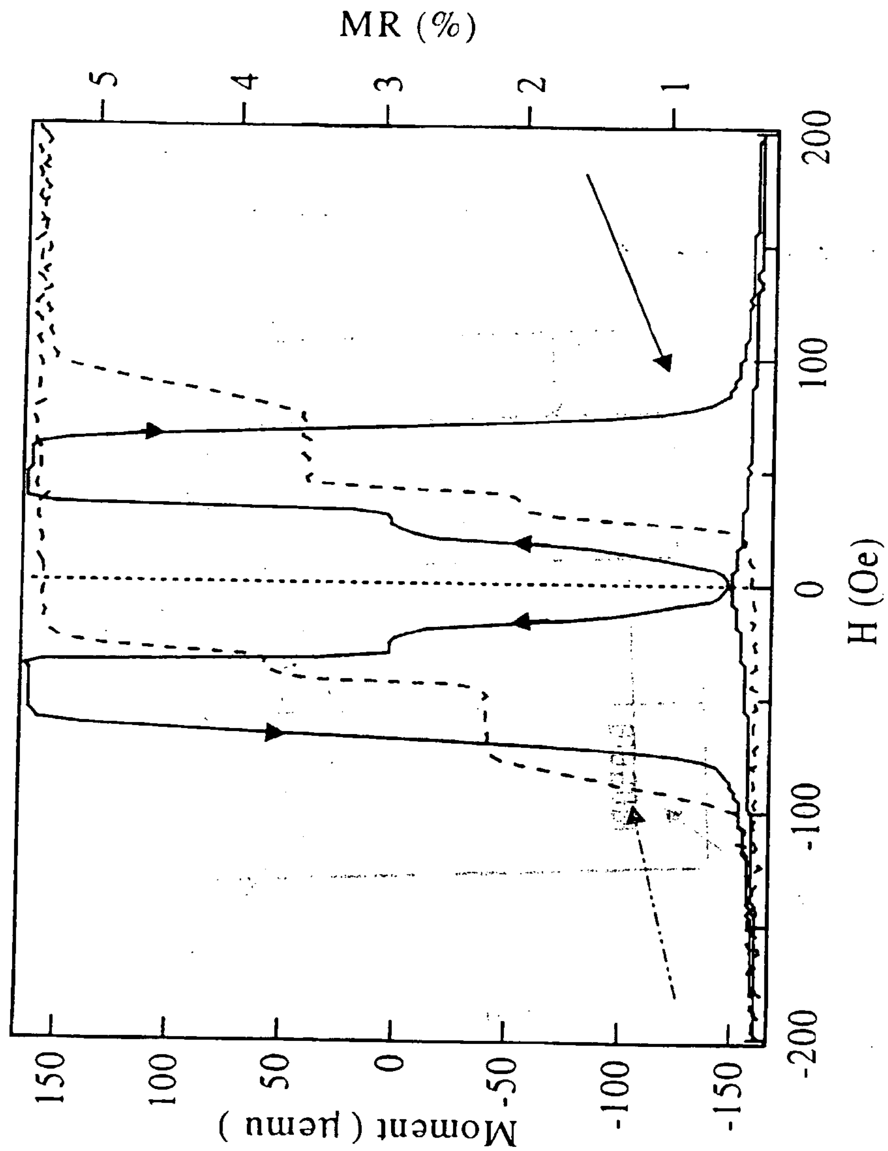
MR (%)
5
4
3
2
1
150
100
50
0
-50
-100
-150
Moment (μemu)
-200
-100
0
100
200
H (Oe)

Fig. 3

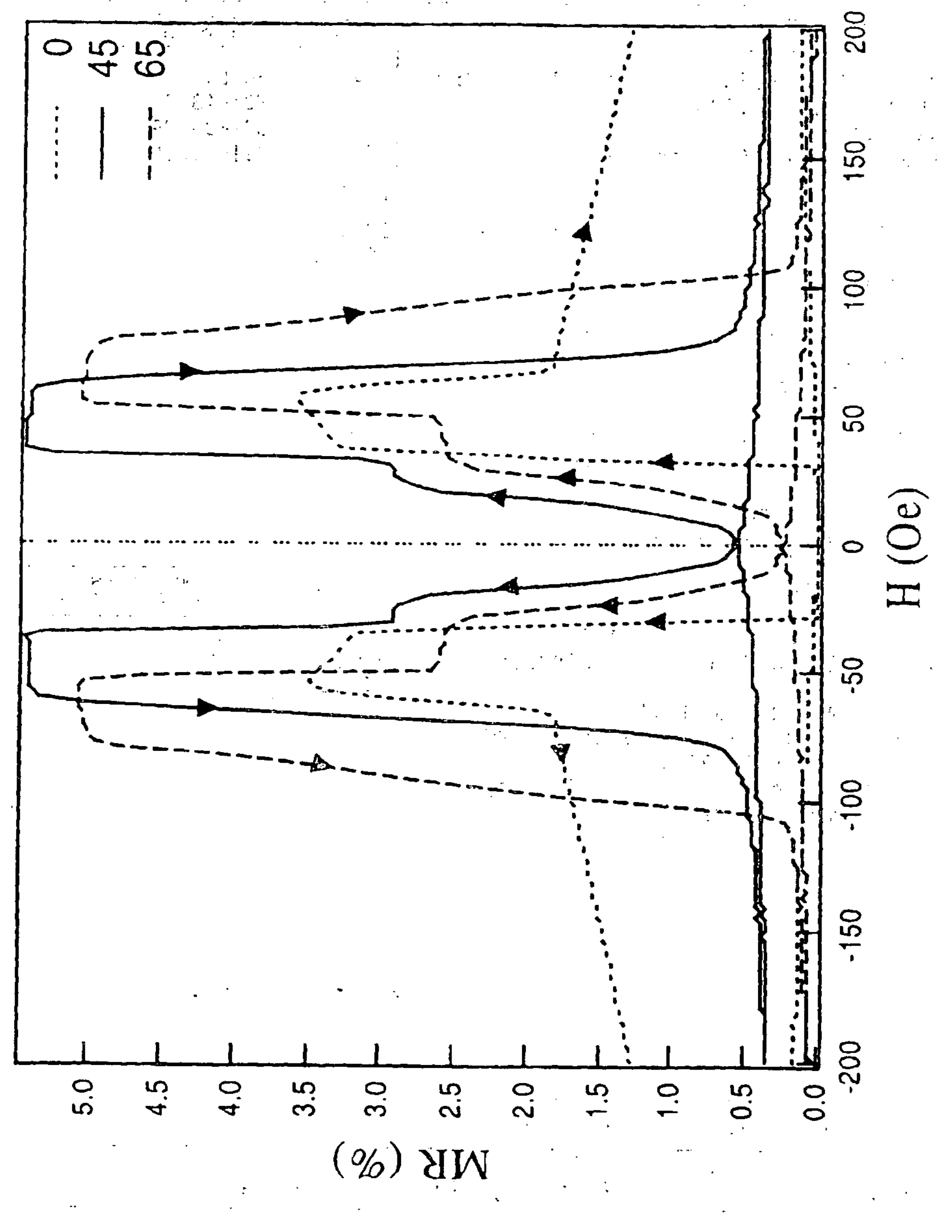
MR (%)
H (Oe)
0
45
65
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
-200 -150 -100 -50 0 50 100 150 200

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 87 0160

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	WO 98 14793 A (BERG HUGO VAN DEN ;SIEMENS AG (DE)) 9 April 1998 * abstract * * page 21, line 10 - line 35 *	1-4,10, 11	H01L43/12 H01L43/08 G01R33/09 G11C11/15
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Place of search	Date of completion of the search	Examiner
THE HAGUE	8 January 1999	De Laere, A

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